Forest Ecology and Management 389 (2017) 96–104

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Vitality fertilization balanced tree nutrition and mitigated severity of *Sirococcus* shoot blight on mature Norway spruce

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ARTICLE INFO

Article history:
Received 9 August 2016
Received in revised form 15 December 2016
Accepted 18 December 2016

Keywords:
Disease tolerance
Imbalanced tree nutrition
Picea abies
Shoot blight
Sirococcus conigenus
Vitality fertilization

ABSTRACT

The effects of vitality fertilization on needle nutrient status and symptom development of *Sirococcus* shoot blight (SSB) were examined in a long-term, single-tree fertilization experiment in a 90-yr old Norway spruce stand on acidic soil. Trees showing severe symptoms of SSB ("symptomatic trees", N = 72) and trees with less than 5% of the current-year shoots symptomatic of SBB ("asymptomatic trees", N = 72) were selected among the dominant and co-dominant trees within the stand and randomly assigned to three fertilization treatments: unfertilized control, dolomitic liming and gypsum & kieserite fertilization. Concentrations of macronutrients were determined in healthy current year needles of symptomatic and asymptomatic trees 3 and 6 years after fertilization and compared with the status in autumn prior to fertilizer treatment. Severity of SSB was rated yearly from 2001 to 2006 by estimating the percentage of affected current-year shoots in the crown in order to assess evolution of disease severity due to changes of nutritional status of the host.

Both fertilizer treatments significantly increased foliar Ca and Mg concentrations, and as a result the primary differences in nutrient status between symptomatic and asymptomatic trees disappeared. Thus, vitality fertilization mitigated insufficient Ca and Mg supply that characterized symptomatic trees prior to fertilization, and balanced tree nutrition. Application of the water soluble Ca- and Mg-fertilizer (gypsum & kieserite-variant) induced a quick but only short-term fertilization effect whereas dolomitic liming resulted in significantly higher Ca and Mg concentrations compared to control 3 as well as 6 years after fertilization. In contrast, Ca- and Mg-deficiencies further intensified in the unfertilized trees.

Balanced tree nutrition also mitigated disease severity of the fertilized trees and promoted tree recovery, indicating that the elements Ca and Mg are putatively involved in disease tolerance. Best results were achieved by fertilization with a water soluble Ca- and Mg-fertilizer which resulted in an 18.9% reduction of disease severity, assessed by the number of diseased shoots per tree, within five years. While dolomitic liming also promoted tree recovery (reduction in disease severity was 11.8%), in the unfertilized control variant a 3.5% increase was observed in the same period. Reduction in disease severity differed significantly from the control for both fertilizer treatments whereas differences between fertilizer treatments were not significant.

Results of this study revealed that balanced nutritional status of mature Norway spruce due to vitality fertilization was associated to reduced symptom development of *Sirococcus* shoot blight.

1. Introduction

Sirococcus conigenus (DC.) P.F. Cannon & Minter is a fungal pathogen that causes shoot blight and seedling death of numerous conifer species throughout much of the northern hemisphere (Hartig, 1890; Smith, 1973; Shahin and Claflin, 1978; Sutherland, 1987; Sanderson and Worf, 1986; Farr et al., 1989; Halmschlager et al., 2000a). It was first described in 1796 from cone scales of Norway spruce by Persoon (Cannon and Minter, 1983) whereas the disease was first reported in 1890 from Germany by Hartig. Colonization of cone scales occurs abundantly on Pinaceae including spruce (e.g. *Picea abies, P. engelmannii, P. glauca, P. pungens, P. mariana, P. sitchensis, P. spinulosa* – Persoon, 1796; Sutherland

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http://dx.doi.org/10.1016/j.foreco.2016.12.019
0378-1127/

et al., 1981; Sutherland, 1987; Kirisits et al., 2007; Kowalski, 2010) and pine species (*Pinus nigra*, *P. ponderosa*, *P. resinosa* and *P. sylvestris* among others – Canada, Department of the Environment, Forestry Service, 1982; Vujanovic et al., 2000; Smith and Stanosz – pers. comm.). Infected cones can serve as an important inoculum source and may also lead to the infection of seeds, resulting in development of seedling blight (Peterson and Smith, 1975; Sutherland, 1987; Motta et al., 1993; Mottinger-Kroupa et al., 2000; Kirisits et al., 2007; Kowalski, 2010). Infection of the current year shoots occurs during shoot elongation in spring with rain-splashed conidia disseminated from pycnidia produced on cones and necrotic needles and stems (Sutherland, 1987; Halmschlager et al., 2000a). Severe damage has been found at all stages of host development both in natural stands and in plantations (Anglberger et al., 2003; Smith and Stanosz, 2008).

In Central Europe epidemics of *S. conigenus* mainly occur on Norway spruce (Hartig, 1893; Rudolph, 1898; Klein, 1987; Minerbi, 1987; Wulf and Maschning, 1992; Neumüller, 1994; Anglberger, 1998; Anglberger and Halmschlager, 2003; Stetter et al., 2004; Blaschke et al., 2009; Kowalski, 2010). In Austria the most recent outbreak has been observed since the early 1980s (Neumüller, 1994; Halmschlager et al., 1998, 2000a,b) and damage was found to be highest in secondary spruce forests on poor and acidified soils (Anglberger and Halmschlager, 2003; Stetter et al., 2004). According to recent estimates *Sirococcus* shoot blight has become a major destabilizing factor on about 6500 ha of spruce forests in the province of Upper Austria (Reisenberger, 2007). A similar situation was detected in the neighboring Eastern Bavaria, where 850 ha are affected and another 240 ha decline and need to be harvested long before they reach the prescribed rotation age (Stetter et al., 2004).

Symptomatic trees showed a significantly reduced radial and height growth in a 20-year-old plantation which resulted in an estimated loss of volume increment of 45% (Halmschlager et al., 2000b), whereas in mature Norway spruce a volume increment loss of 37% was detected in a recent study, carried out on the same plot as the present study (Huber et al., 2009).

Furthermore, the study of Anglberger et al. (2003) revealed insufficient Mg and Ca supply and enhanced N/Mg and N/Ca ratios in the needles of symptomatic trees, whereas in asymptomatic trees all needle element concentrations were above the threshold for deficient supply. Although *S. conigenus* was also encountered in asymptomatic trees, no symptoms developed, which indicates latent infections by the pathogen. Such a "tolerance to infection" is defined as the ability of a host to limit the impact of a pathogen on host health, performance and fitness (Agrios, 2009). As asymptomatic trees with balanced nutrition maintained performance and showed no or only little damage, we hypothesized a close relation between supplies of base cations, in particular calcium and magnesium, and severity of *Sirococcus* shoot blight on Norway spruce (Anglberger et al., 2003).

Katzensteiner and Glatzel (1997) describe cumulative negative effects of historical land use like litter raking, conversion of mixed forest stands to pure Norway spruce and air pollution upon foliar nutrient status of forest trees and in particular of base cation supply which may potentially have detrimental effects upon tree tolerance to pathogen infections. To mitigate these negative effects, vitality fertilization (i.e. fertilization that aims to improve vigor/vitality of trees and enhance tree resistance or tolerance to disease, alleviate soil acidification, improve soil biological activity and maintain a balanced nutrient cycling) has successfully been applied to nutrient deficient stands on acidic soils. Long-term effects upon nutrition, vitality and growth depend on the type of fertilizer applied. Katzensteiner et al. (1995) could show that responses of these parameters to slow release fertilizers containing sufficient amounts of Mg are superior compared to easily soluble neutral salts. In continuous cover forestry (Pommerening and Murphy, 2004) vitality fertilization may be a measure to stabilize *Sirococcus*-infested secondary spruce forests on poor and acidified soils while slowly converting them into more resilient mixed stands. Thus we wanted to test the hypothesis that improved nutrient supply will have an impact upon *Sirococcus* shoot blight and promote recovery of diseased trees.

A limitation of previous studies indicating positive effects of fertilization (Jandl et al., 2000; Anglberger and Halmschlager, 2003) was that disease severity and nutritional status of trees was not assessed prior to fertilization. Instead, comparisons were made between plots that had been fertilized several years before with adjacent unfertilized control plots. Furthermore, these investigations were based on practical field trials initiated by practitioners and their layout did not follow a randomized experimental design. Therefore a single-tree fertilization experiment with a random design in which tree health and nutritional status were recorded prior to treatments was established in 2001 at a site already investigated by Anglberger et al. (2003). Preliminary results of Halmschlager et al. (2007) proved a mitigating effect of the fertilizer treatments upon disease severity. Within the same experiment Huber et al. (2009) found significant fertilization effects on basal area increment. Both studies did not consider the nutritional status of fertilized trees. Hence, the aim of the present study was to determine if a change towards balanced nutritional status due to vitality fertilization leads to a parallel reduction of *Sirococcus* shoot blight severity.

We hypothesize:

- Ca and Mg fertilization will balance nutrition of trees affected by *Sirococcus* shoot blight.
- Balanced tree nutrition will mitigate disease severity and promote tree recovery.
- Tree response depends on the type of Ca/Mg fertilizer applied (easily soluble neutral salt versus alkaline reacting dolomitic lime).

2. Material and methods

2.1. Study area and experimental stand

The field experiment was carried out in the same stand in the Kobernausser Wald, Upper Austria (48°04′42″ N, 13°14′19″ E) that had already been investigated prior to fertilization by Anglberger et al. (2003) and that also had been used for our study on the effects and interrelationships between disease severity of *Sirococcus* shoot blight, fertilization treatment and increment of mature Norway spruce (Halmschlager et al., 2007; Huber et al., 2009). The Kobernausserwald, an area of about 150 km^2, is located in the western part of Upper Austria between 450 and 750 m a.s.l. The 30-year average annual precipitation (1971–2000) at the nearest weather station is 1179 mm, varying from 800 to 1400 mm. The mean annual temperature is 7.8 °C (Anonymous, 2006). Due to tertiary gravel as parent material for soil formation, the soils in the study area were generally characterized by low pH-values and low fertility (Jenner, 1979; Jandl, 1993). This was also true for the experimental stand, characterized by Dystric Cambisols (IUSS, 2006) with relatively poor levels of available nutrients partly due to weathering resistant quartz rich gravel as parent material for soil formation (Anglberger et al., 2003). In addition, former litter raking (Reinisch, 1873) and the conversion of mixed stands into secondary spruce forests (Jenner, 1979) had detrimental effects upon soil pH and fertility in many parts of the Kobernausserwald. In the second half of the 20^{th} century the area was also prone to high rates of air pollution, in particular of sulfur and nitrogen (Berger and Katzensteiner, 1994). Typical soil properties are given